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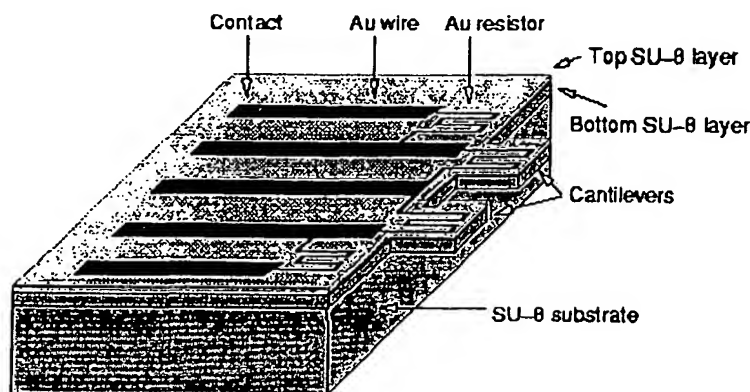
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(54) Title: FLEXIBLE STRUCTURE WITH INTEGRATED SENSOR/ACTUATOR



(57) Abstract: A polymer-based flexible structure with integrated sensing/actuator means is presented. Conventionally, silicon has been used as a piezo-resistive material due to its high gauge factor and thereby high sensitivity to strain changes in a sensor. By using the fact that e.g. an SU-8 based polymer is much softer than silicon and that e.g. a gold resistor is easily incorporated in SU-8 based polymer structure it has been demonstrated that a SU-8 based cantilever sensor is almost as sensitive to stress changes as the silicon piezo-resistive cantilever.

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FLEXIBLE STRUCTURE WITH INTEGRATED SENSOR/ACTUATOR

FIELD OF THE INVENTION

5 The present invention relates to a flexible structure comprising an integrated sensing/actuating element or elements. The integrated sensing/actuating elements are electrically accessible and at least partly encapsulated in a flexible and electrically insulating body so that the flexible structure may be operable in e.g. an electrically conducting environment.

10

BACKGROUND OF THE INVENTION

The use of e.g. SU-8 based (glycidyl ether of bisphenol A) polymers within the MEMS field has been exponentially growing during the last couple of years.

15 SU-8 based polymers are known in the art as being an epoxy-based photosensitive polymer which may be used as a negative photoresist. SU-8 based photoresists are sensitive to light exposures in the near UV region - typically in the wavelength range from 365 nm to 436 nm. The fact that SU-8 based polymers are very chemically and thermally resistant makes it possible to use

20 this group of polymers as a component materials. Due to its capability of defining layers with thickness' between 1 μ m and 1 mm with high aspect ratios (>20), SU-8 based polymers have been a popular and cheap alternative to silicon for the fabrication of passive components. Such components include micro-channels, micro-molds for electroplating or masters for hot embossing.

25 Passive SU-8 based atomic force microscopy (AFM) cantilevers have also been demonstrated.

WO 00/66266 discloses silicon-based micro-cantilever, micro-bridge or micro-membrane type sensors having piezo-resistive readout so as to form an integrated readout mechanism. Such micro-cantilevers, micro-bridges or micro-

30 membranes sensors are suitable for use in micro-liquid handling systems so as to provide an integrated detection scheme for monitoring physical, chemical and biological properties of liquids handled in such systems.

Since silicon exhibits 1) superior mechanical behavior and 2) has a very high piezo-resistive coefficient, silicon has been the obvious material when sensors with integrated readout were to be designed and fabricated.

5 However, in case silicon-based sensors with integrated readout are to be operated in a conducting liquid environment - such as in micro-liquid handling systems, encapsulation of the electronic circuit constituting the integrated readout is required - otherwise, the electronic circuit will short-circuit causing the integrated readout and thereby the sensor as a whole to fail to operate.

10

Furthermore, fabrication of silicon-based sensor are rather complicated due to the comprehensive process sequence required in order to fabricate such sensors. A consequence of the comprehensive process sequence is directly reflected in the fabrication costs causing the fabrication of silicon-based sensors
15 to be very expensive.

US 6,087,638 discloses a thermal actuator comprising an inner conductive material encapsulated in a non-conductive *expansive* material, such as polytetrafluoroethylene (PTFE) - see column 2, line 24. Preferably, the conductive material is formed as a corrugated copper heating element (see column 2, lines 23-24) so as to increase the rate of thermal transfer to the non-conductive expansive material encapsulating the copper heating element. The thermal actuator of US 6,087,638 is preferably applied in ink jet printers where ink is ejected through nozzles when the thermal actuator is activated.

25

It is evident that it is the non-conductive *expansive* material that causes the actuator of US 6,087,638 to deform/bend. This deformation/bending is induced by exposing the non-conductive material to heat via the thermal actuator which causes the non-conductive material to expand whereby the actuator as a whole is activated.

30

The fact that heat is what causes the actuator of US 6,087,638 to bend requires that a significant amount of power needs to be provided to the actuator. Even further, in case the actuator of US 6,087,638 is to be applied in mi-

cro-liquid handling systems the heating of the actuator may cause the temperature of the surrounding liquid to increase which, in some situations, would be disadvantageous. In a worst case scenario, the increased temperature could initiate a chemical reaction in the liquid.

5

It is an object of the present invention to provide a solution to the above-mentioned disadvantages of conventional systems. Thus, it is an object of the present invention to provide a sensor/actuator configuration including an encapsulating and electrically insulating body so that the sensor/actuator may be
10 immersed directly into a conducting liquid environment without the use of a separate encapsulation layer so as to avoid short-circuit of electronic components forming the integrated readout/integrated actuator. An advantage of such a sensor/actuator is that it can be operated in conducting liquid environment without the use of the before-mentioned encapsulation layer.

15

It is a further object of the present invention to provide a sensor/actuator with integrated readout/actuator which is cheaper and easier to fabricate compared to conventional systems.

20 SUMMARY OF THE INVENTION

The above-mentioned objects are complied with by providing, in a first aspect, a flexible structure comprising integrated sensing means, said integrated sensing means being at least partly encapsulated in a flexible and electrically
25 insulating body, said integrated sensing means further being adapted to sense deformations of the flexible structure.

The flexible structure may be a micro-cantilever having a rectangular form. Typical dimensions of such micro-cantilever may be: width: 50-150 μm ,
30 length: approximately 200 μm , and thickness 1-10 μm . Alternatively, the flexible structure may be a micro-bridge having its ends attached to the walls of e.g. an interaction chamber in an liquid handling system. The dimensions (wide, length and thickness) of a micro-bridge may be similar to the dimensions of the micro-cantilever. Alternatively, the flexible structure may be a

membrane-like structure forming part of e.g. the side-walls of an interaction chamber. The flexible structure may also be a stress sensitive membrane - example for use in pressure sensors.

- 5 The flexible and electrically insulating body may be a polymer-based body, such as a photosensitive polymer. A first and a second polymer layer may form this flexible polymer-based body where the integrated sensing means is embedded into the first and/or the second polymer layer.
- 10 The integrated sensing means (sensing element or elements) may be a resistor formed by a conducting layer - for example a metal layer such as a gold layer. The resistance of the resistor is dependent on deformations of the flexible structure whereby deformations of the flexible structures may be detected. Alternatively, the conducting layer may comprise a semiconductor material,
- 15 such as silicon. In case of silicon, the resistor will be a so-called piezo-resistor which may be integrated in the polymer-based body using sputtering.

An SU-8 based polymer may form the flexible polymer-based body. Other suitable groups of photosensitive polymers are polyimide and BCB cyclotene

20 polymers. In case the polymer-based body is formed by two layers of polymers these layers may both be SU-8 based, such as XP SU-8, polyimides or BCB cyclotene polymers or any combination thereof.

In the following, the present invention will be described in detail with reference to SU-8 based polymers only. However, this should not be regarded as a

25 limitation with regard to choice of polymer material - polyimide and BCB cyclotene polymers could be used as well.

As already mentioned, SU-8 based polymers are known in the art as being an

30 epoxy-based negative photoresist which are sensitive to light exposures in the near UV region (typically in the range 365 - 436 nm). SU-8 based polymers are characterized as being chemically and thermally stable which makes them attractive for device proposes.

The flexible structure may further comprise a substantially rigid portion so as to form a chip, the chip further comprising an integrated electrical conductor being at least partly encapsulated in an electrically insulating body, said integrated electrical conductor being connected to the integrated sensing means
5 and being electrically accessible via a contact terminal on an exterior surface part of the substantially rigid body.

The substantially rigid portion may be that part of a micro-cantilever, which is supported by a substrate. As well as the flexible structure, the substantially
10 rigid body may be formed by a first and a second polymer layer. The integrated electrical conductor may be at least partly embedded into the first and/or the second polymer layer. These polymer layers may be SU-8 based polymer layers, such as XP SU-8 polymer layers.

15 The integrated electrical conductor may be formed by a metal layer - for example a gold layer. Alternatively, the integrated electrical conductor may comprise a semiconductor material - for example sputtered silicon.

The chip may further comprise at least three resistors, the at least three resistors forming part of the substantially rigid portion of the chip. The at least
20 three resistors may be embedded into the first and/or the second polymer layer of the substantially rigid portion. In a preferred embodiment the chip comprises three resistors.

In a second aspect, the present invention relates to a chip comprising two or
25 more flexible structures according to the first aspect, said chip further comprising additional resistors on a substantially rigid portion of the chip.

In one embodiment, the chip comprises two flexible structures according to the first aspect, the chip further comprising a substantially rigid portion comprising integrated electrical conductors each being at least partly encapsulated
30 in an electrically insulating body, a number of said integrated electrical conductors being connected to the integrated sensing means and being electrically accessible via contact terminals on an exterior surface part of the substantially rigid portion. The chip may further comprise two resistors, the two resistors forming part of the substantially rigid portion of the chip.

The substantially rigid portion may comprise a first and a second polymer layer, and wherein the integrated electrical conductors and the two resistors are at least partly embedded into the first and the second polymer layer of the substantially rigid portion of the chip

5

Preferably, these four resistors are connected so as to form a Wheatstone Bridge in combination.

The substrate may be a polymer substrate, such as a SU-8 based polymer
10 substrate, or, alternative, the substrate may be e.g. a semiconductor material, a metal, glass, or a plastic substrate. A suitable semiconductor material is silicon.

In a third aspect, the present invention relates to a sensor for measuring the
15 presence of a substance in a fluidic, Such sensor may comprise a chip according to the second aspect. Such sensor could be a micro-cantilever, micro-bridge or micro-membrane type sensor having integrated readout. A closed micro-liquid handling system allows laminated flows of different liquids to flow in the channel without mixing, which opens up for new type of experiments
20 and which reduces noise related to the liquid movement. Neighbouring or very closely spaced micro-cantilevers, micro-bridges or micro-membranes can be exposed to different chemical environments at the same time by:

- Laminating the fluid flow vertically in the micro-channel into two or more
25 streams, so that micro-cantilevers or micro-membranes on opposing sides of the micro-channel are immersed in different fluids, or so that a micro-cantilever, micro-bridge, or micro-membrane is exposed to two different fluids.
- 30 - Laminating the fluid flow horizontally in the micro-channel, so that micro-cantilevers or micro-bridges recessed to different levels in the micro-channel or micro-membranes placed at the top and at the bottom of the channel are exposed to different fluids.

In this way, changes in viscous drag, surface stress, temperature, or resonance properties of adjacent or closely spaced micro-cantilevers, micro-bridges or micro-membranes induced by their different fluid environments, can be compared.

5

Neighbouring or very closely spaced micro-cantilevers, micro-bridges or micro-membranes can be coated with different chemical or biological substances for immersing adjacent or neighbouring micro-cantilevers, micro-bridges or micro-membranes in different fluids.

10

In micro-cantilever, micro-bridge or micro-membrane based sensors, the liquid volume may be minimised in order to reduce the use of chemicals and in order to obtain a system which is easy to stabilise thermally.

- 15 In a fourth aspect, the present invention relates to an actuator comprising a flexible structure, said flexible structure comprising integrated actuator means being electrically accessible and being at least partly encapsulated in a flexible and electrically insulating body, said integrated actuator means being adapted to deform upon accessing the integrated actuator means electrically thereby
20 inducing deformations of the flexible structure in accordance with deformations of the integrated actuator means.

The integrated actuator means (actuator element or elements) may comprise at least one metal layer. The flexible and electrically insulating body may be a
25 polymer-based body formed by for example an SU-8 based polymer. In one embodiment, two different metal layers may be slightly heated whereby actuation may be achieved via the bimorph effect due to different thermal expansions of the two metal layers.

- 30 In a fifth aspect, the present invention relates to a chip comprising an actuator according to the fourth aspect, further comprising a polymer-based substrate supporting a substantially rigid portion of the chip. The substrate may be formed in a photosensitive polymer, such as an SU-8 based polymer. Alterna-

tively, the substrate may be a silicon-based substrate supporting the substantially rigid portion of the chip.

In a sixth aspect, the present invention relates to a method of manufacturing
5 a chip, the method comprising the steps of

- providing a first electrically insulating layer,
- 10 - patterning the first electrically insulating layer so as to form a first part of a flexible cantilever,
- providing, onto a first area of the layer forming the first part of the flexible cantilever, a first conducting layer, and patterning the first conducting layer so as to form at least one conductor on the first area of
15 the patterned first electrically insulating layer,
- providing, onto a second and different area of the layer forming the first part of the flexible cantilever, a second conducting layer, and patterning the second conducting layer so as to form at least one resistor
20 on the second area of the patterned first electrically insulating layer, and
- 25 - providing, onto the first and second areas of the layer forming the first part of the flexible cantilever, a second electrically insulating layer so as to at least partly encapsulate the at least one conductor and the at least one resistor, and patterning the second electrically insulating layer so as to form a second part of a cantilever.

Preferably, the at least one conductor on the first area is connected to at least
30 one resistor on the second area.

The electrically insulating layers may be polymer layers - for example SU-8 based polymer layers. The conducting layers may be metal layers - for example gold layers.

The method may further comprise the steps of providing a third layer onto the second electrically insulating layer, and patterning the third layer so as to form a substrate that only supports the first area of the second electrically insulating layer. The third layer may be a polymer-based layer, such as an SU-8 based layer. Alternatively, the third layer may be a silicon-based layer. The method may further comprise the steps of

- providing a sacrificial layer on a silicon wafer, upon which the first electrically insulating layer is provided, and

- removing the silicon wafer after providing and patterning of the third layer.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will now be explained in further details with reference to the accompanying figures, where

figure 1 shows a process sequence for the fabrication of a polymer-based cantilever - here a SU-8 based polymer body,

figure 2 shows an example of a complete chip design,

figure 3 shows optical images of cantilevers with integrated meander-type resistor, and

figure 4 shows the relative change in resistance as a function of the cantilever deflection.

DETAILED DESCRIPTION OF THE INVENTION

As previously mentioned, the flexible structure may be the movable part of a cantilever beam, the movable part of a micro-bridge, or the movable part of a diaphragm. A detailed description of the present invention will now be pro-